

# THE DYNAMICAL INTERACTION OF AGN WITH THEIR GALAXIAN ENVIRONMENTS

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## Abstract

Jet-driven shocks are responsible for an important fraction of the emission of the narrow-line regions (NLRs) in many classes of AGN. However, this cannot explain all observations. It is clear that the remaining sources are photoionised by the active nucleus. The 2-d hydrodynamic models from the RSAA group support an evolutionary scenario whereby the shock-excited NLRs are initially jet-driven but later, ionizing photons from the central engine replace shocks as the main excitation mechanism and shock induced star formation may also become important. In their photoionized phase, dusty and radiation-pressure dominated evolution produces a self-regulated NLR spectrum. This model also explains the coronal emission lines and fast ( $3000 \text{ km s}^{-1}$ ) outflows seen in some Seyferts.

## 1. Shock-Driven Radio Galaxies

There is increasing evidence that the narrow-line regions (NLRs) associated with many classes of active galactic nuclei (AGN) have a complex dynamical and excitation evolution. Evidence for a cocoon of strong, auto-ionising and radiative shocks (see the theory by Dopita & Sutherland 1995, Dopita & Sutherland 1996 and Bicknell Dopita & O'Dea 1997) is particularly compelling for many luminous classes of radio galaxies. These include the steep-spectrum radio sources (CSS), Fanti et al. 1990, unbeamed Gigahertz-peaked sources (GPS) (see the recent review by O'Dea et al. 1998), compact symmetric objects (CSO) (Wilkinson et al. 1994, and references therein) or compact double sources (CD) Phillips & Mutel 1982. Together, these represent an appreciable fraction (10-30%) of luminous radio sources. Not only are such sources very luminous at

radio frequencies, but they also are very luminous in optical emission lines, and spectra by Gelderman and Whittle (1994,1996) reveal intense “narrow line” emission with line ratios similar to those of Seyfert 2 galaxies. For these objects, the line emission scales with radio power, and the continuity of properties across these different classes of sources argues strongly that the kinetic energy supplied by the radio-emitting jets may provide a substantial fraction of the power radiated at other wavelengths by shocked gas associated with the NLRs of these galaxies.

The high redshift radio galaxies present us with a statistically significant sample in which to study UV line ratio behaviour and so investigate the fraction of the NLR emission produced by shocks, and the fraction by photoionization. The study by Best et al. (2000a,b) revealed an extraordinary result for powerful 3C radio galaxies with  $z \sim 1$ . They find that both the UV line profiles and the UV line ratio diagnostics imply that, when the scale of the radio lobes is such that they are still able to interact with the gas in the vicinity of the galaxy, they are predominantly shock-excited, but when the lobe has burst out into intergalactic space, the ionised gas left behind is predominantly photoionized. The ratio of fluxes in the different classes of source suggests that the energy flux in the UV radiation field is about 1/3 of the energy flux in the jets. Thus, both shocks and photoionization are important in the overall evolution of radio galaxies. This result, if confirmed for radio sources in general, would prove that the properties of the radio jet are intimately connected with the properties of the central engine.

Very distant radio galaxies have been recently studied by De Breuck (2000). He finds that diagnostic diagrams involving C IV, He II and C III] fit to the pure photoionization models, but that the observed C II]/C III] requires there to be a high-velocity shock present. He argues that composite models would be required to give a self-consistent description of all the line ratios, and that these may require a mix of different physical conditions as well.

A fine example of such a source is provided by the  $z \sim 3.8$  radio galaxy 4C 41.17 has recently been studied in detail by Bicknell Dopita & O’Dea (2000). This object consists of a powerful “double-double” radio source embedded in a  $190 \times 130$  kpc  $\text{Ly}\alpha$  halo (Reuland et al. 2002) and shows strong evidence for jet-induced star formation at  $3000 \text{ M}_{\odot} \text{ yr}^{-1}$  associated with the inner radio jet. Bicknell Dopita & O’Dea (2000) constructed a model involving the interaction of a high-powered jet with an energy flux of  $\sim 10^{46} \text{ ergs s}^{-1}$  interacting with a dense cloud. Likewise, the outer jet has imposed a strong dynamical signature of outflow with velocities in excess of  $500 \text{ km s}^{-1}$  in the line-emitting gaseous halo.

On the basis of such observations, we can propose a simple evolutionary scenario for such radio sources. First, the accretion onto the central engine drives a radio jet which is first visible as a GPS source, but later evolves into a powerful 3C-like double lobe radio source. During the time that the scale of the radio lobes is less than 10-30 kpc, the interactions with the surrounding galactic medium are strong, and the NLR is predominantly shock-excited. The radio jets bore out “ionization cones” which are responsible for the “alignment effect” seen in the NLR of such sources. At late phases, the ionized gas is either photoionized by the central source, or by shock-induced star formation that must inevitably take place along the boundaries of the old shocked cocoon.

## 2. Photoionisation-Dominated AGN

Dynamical signatures of strong shocks are apparent in only 5 – 10% of Seyfert (eg. Whittle 1996). Many of these are the more radio-luminous galaxies including Mrk78 (Pedlar et al. 1989), NGC2992 (Allen et al. 1999) or Mrk 1066 (Bower et al. 1995). The power requirements are modest, typically  $10^{41}$  and  $10^{44}$  ergs  $s^{-1}$  *c.f* those of luminous radio sources ( $10^{45}$  -  $10^{46}$  erg  $s^{-1}$ ). The remainder of Seyfert galaxies appear to be photoionised (Evans et al. 1999).

In the gas-rich and cloudy circumnuclear environments, light and low-power radio jets are readily disrupted and suffer entrainment from the surrounding material, and molecular clouds are crushed in the high-pressure environment. This is clearly demonstrated by 2-d hydrodynamic simulations by Bicknell Saxton & Sutherland (2002), and in preparation. Here, shock velocities are generally lower and although shocks may be still important in shaping the circum-nuclear medium, photoionisation is more important for its excitation.

A curious feature of the spectra of the NLR of photoionised Seyfert 2 galaxies is that nearly all are located in a region showing less than 0.8 dex variation in  $[OIII] \lambda 5007\text{\AA}/H\beta$ ,  $[NII] \lambda 6583\text{\AA}/H\alpha$  or  $[OI] \lambda 6300\text{\AA}/H\alpha$  ratios, according to extensive observations by Véron & Véron-Cetty 2000. Within individual galaxies, spatial variations in these line ratios are even tighter (Allen et al. 1999). The observations constrain the dimensionless ionization parameter,  $U$ , in the range  $-3 < \log U < -2$ . This would require that the density of the photoionized clouds falls off roughly as the inverse square of their radial distance.

Theoretical insight into this problem has recently been forthcoming (Dopita et al. 2002). Because clouds lying in the path of the jet and its surrounding high-pressure cocoon are crushed at relatively low velocity, then any dust mixed with the cloud gas is likely to survive. If the cen-

tral source produces UV photons with high local ionisation parameter, the dusty ionised gas is compressed, raising the pressure close to the ionisation front to match the radiation pressure in the EUV radiation field. This regulates the apparent ionisation parameter, and ensures that the density of photoionized clouds varies as  $R^{-2}$ . Each photoablating cloud is surrounded by a coronal medium in which the local ionization parameter reflects the “true” ionisation parameter delivered by the central source, and each has a dusty photo-accelerated radial tail (c.f. Cecil et al. 2002). In this model, the terminal velocity of outflow should correlate with the strength of the coronal line emission, explaining the observations of Zamanov et al. 2002 and Rodriguez-Ardila et al. 2002.

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